

Blood ties: the real nature of the LMC binary globular clusters NGC 2136 and NGC 2137¹

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ABSTRACT

We have used a sample of high-resolution spectra obtained with the multi-fiber facility FLAMES at the Very Large Telescope of the European Southern Observatory, to derive the kinematical and chemical properties of the two young Large Magellanic Cloud globular clusters NGC 2136 and NGC 2137. These two clusters represent a typical example of LMC cluster pair suspected to be bound in a binary system: indeed the cluster centers of gravity have an angular separation of less than 1.4 arcmin in the sky. The spectral analysis of seven giants in NGC 2136 and four in NGC 2137 reveals that the

two clusters share very similar systemic radial velocities, namely $V_r = 271.5 \pm 0.4$ km/s ($\sigma = 1.0$ km/s) and $V_r = 270.6 \pm 0.5$ km/s ($\sigma = 0.9$ km/s) for NGC 2136 and NGC 2137, respectively, and they have also indistinguishable abundance patterns. The iron content is $[\text{Fe}/\text{H}] = -0.40 \pm 0.01$ dex ($\sigma = 0.03$ dex) for NGC 2136 and -0.39 ± 0.01 dex ($\sigma = 0.01$ dex) for NGC 2137, while the $[\alpha/\text{Fe}]$ ratios are roughly solar in both clusters. These findings suggest that the two clusters are gravitationally bound and that they formed from the fragmentation of the same molecular cloud that was chemically homogeneous. This is the first firm confirmation of the binary nature of a LMC cluster pair. The most likely fate of this system is to merge into a single structure in a time-scale comparable with its orbital period.

Subject headings: stars: abundances — globular clusters: individual (NGC 2136, NGC 2137) — Magellanic Clouds — techniques: spectroscopic

1. Introduction

One of the most intriguing feature of the Large Magellanic Cloud (LMC) globular clusters (GCs) system is the large population of binary clusters that this galaxy harbors. The catalogue by Dieball, Müller & Grebel (2002) includes a total of 473 candidate multiple (binary or triple) stellar clusters and associations with angular distances ≤ 1.4 arcmin (corresponding to a projected distance of 20 pc when a distance modulus of 18.5 mag is assumed) and ages less than ~ 1 Gyr. This sample corresponds to about 10% of the entire stellar clusters population in the LMC. Similar binary systems are observed also in other galaxies, like the Small Magellanic Cloud (SMC) (Hatzidimitriou & Bhatia 1990), M31 (Holland, Fahlman & Richer 1995) and NGC 5128 (Minniti et al. 2004). In contrast, in our Galaxy the only recognized case is the open cluster pair NGC 869/NGC 884.

There are some possible scenarios to explain the nature of the binary clusters: (i) two clusters at different distances appear as a binary system only due to projection effects, lying along the same line of sight; (ii) the clusters were born independently from distinct molecular clouds (likely with different ages and chemical compositions) and subsequently became a bound system after a close encounter or a tidal capture; (iii) the clusters were born from the same molecular cloud (hence with the same age and metallicity) and are gravitationally bound. Based on statistical arguments, Dieball, Müller & Grebel (2002) suggest that the LMC binary clusters population cannot be simply explained in terms of apparent pairs, but a relevant fraction must be bound systems.

While the large number of binary clusters among the young Magellanic globulars is a significant clue, the small projected distance on the sky between two clusters cannot guarantee the effective

¹Based on observations collected at the ESO-VLT under the program 084.D-0933.

blood tie of the objects. Hints on binarity from the ages and photometric metallicities (with uncertainties at a level of 0.2 dex) have been provided for some tens of cluster pairs (see for instance Dieball & Grebel 1998; Hilker, Richtler & Stein 1995; Vallenari, Bettoni & Chiosi 1998). However, a firm validation of that binarity can only be obtained from the combined information of age, chemical abundances from high resolution spectra and radial velocities (V_r) measurements in order to clarify if the system is gravitationally bound and unveil the possible common origin from the same molecular cloud. At present such a binarity validation has not been probed in any LMC cluster pair.

This paper is devoted to address the true nature of the cluster pair NGC 2136/NGC 2137. These are two young GCs with an angular separation of 1.34 arcmin (Bhatia et al. 1991), corresponding to a projected separation of ~ 19.5 pc, assuming a distance of 50 kpc (see left panel in Fig. 1). Previous studies stated that the two clusters share the same age (~ 80 -100 Myr, see Hilker, Richtler & Stein 1995; Dirsch et al. 2000) but no direct chemical and kinematical measurements are available to date.

2. Observations

Observations were performed with the multi-fiber facility FLAMES mounted at the ESO Very Large Telescope in the combined mode UVES+GIRAFFE. Data were acquired under a program devoted to investigate the chemical composition of the LMC GCs and their surrounding fields. The employed grating configuration includes the setups HR 11 and HR 13 for GIRAFFE and the 580 Red Arm for UVES. A total of 5 exposures of ~ 45 min each was secured on the same targets configuration. The reduction of the spectra (including bias subtraction, flat-fielding, wavelength calibration and spectra extraction) was performed with the standard ESO pipelines. Typical signal-to-noise ratio per pixel of the final coadded spectra is of ~ 50 -60. The FLAMES fibers were allocated on giant stars of the two clusters NGC 2136 and NGC 2137 and of the surrounding field. Targets in the innermost 2.5 arcmin from the cluster center have been selected from the SofI near-infrared catalog by Mucciarelli et al. (2006) while outermost objects were chosen from the 2MASS dataset.

It is worth noting that the size of the clusters, their angular separation and the physical size of the FLAMES magnetic buttons do not allow to allocate a large number of fibers on the area covered by two clusters. A total of 22 fibers were finally allocated in the inner 3 arcmin (marked in the right panel of Fig. 1). Here we discuss the kinematical and chemical properties of these stars.

Interestingly enough, Hilker, Richtler & Stein (1995) suggest a possible third component of the system, identifying a faint stellar association located at a distance of ~ 2.4 arcmin from the main cluster and embedded in a common stellar halo (the position of this stellar association is highlighted in the left panel of Fig. 1). As apparent from the right panel of Fig. 1, one FLAMES fiber was allocated also on this loose clump of stars.

3. Radial Velocities and chemical analysis

Radial velocities were derived by using the DAOSPEC code (Stetson & Pancino 2008) and measuring ~ 370 and ~ 140 absorption lines of different elements in the UVES and GIRAFFE spectra, respectively. Typical internal errors (computed as $\sigma/\sqrt{N_{lines}}$) are of 0.05 for UVES and 0.15 km/s for GIRAFFE. The accuracy of the zero-point of the wavelength calibration is checked by measuring several sky emission lines and compared with their restframe positions listed by Osterbrock et al. (1996): the uncertainty in the zero-point has been added in quadrature to the internal error.

The chemical analysis was performed by using the suite of codes by R. L. Kurucz (see Sbordone et al. 2004), aimed to compute model atmospheres, abundances from the observed equivalent widths and synthetic spectra. The employed model atmospheres were computed with ATLAS9, assuming plane-parallel geometry, LTE for all the species and no overshooting.

We used suitable linelists checked against spectral blending, in order to include only transitions predicted to be unblended for the corresponding spectral resolution and parameters. Oscillator strengths are from the most recent version of the Kurucz/Castelli linelist ². Equivalent widths were measured with DAOSPEC. Atmospheric parameters were derived spectroscopically, by requiring (i) no trend between excitation potential and iron abundance to constrain the temperature; (ii) no trend between line strength and iron abundance to constrain the microturbulent velocity, and (iii) the same abundance from neutral and single ionized iron lines to constrain the gravity.

We measured abundances for Fe, Ni, Mg, O, Al, Na, Si, Ca, Ti. Oxygen abundances are derived through spectral synthesis of the forbidden line at 6300 Å. Na abundances were derived from the doublet at 6154-60 Å for all the stars and also from the line at 5688 Å for the stars observed with UVES; departures from LTE were corrected following Lind et al. (2011). The total uncertainty for each abundance ratio was computed by adding in quadrature the internal error (computed as $\sigma/\sqrt{N_{lines}}$) and the uncertainty arising from the atmospheric parameters (the latter computed following the approach by Cayrel et al. 2004).

4. Results

The heliocentric radial velocity V_r distribution for all the 22 giants measured in the region of the two clusters is shown in the upper panel of Figure 2. As can be seen, it is highly peaked at $V_r \sim 270$ km/s. The lower panel of Figure 2 shows metallicities and radial velocities for the stars with $V_r > 230$ km/s. A clear, well defined clump of 11 stars sharing virtually the same radial velocity ($V_r \sim 270$ km/s) and metallicity ($[Fe/H] \sim -0.40$) is visible. Main information for these stars are listed in Table 1 and their position in the *SofI* color-magnitude diagram is shown in the

²<http://wwwuser.oat.ts.astro.it/castelli/linelists.html>

left panel of Fig. 3, together with portions of UVES spectra in the right panel. They are also marked in the right panel of Fig. 1. The close inspection of this map allows to attribute each star to one of the two clusters: we have attributed 7 stars to NGC 2136 and 4 stars to NGC 2137³.

Considering the entire sample of 11 stars, the mean radial velocity turns out to be of 271.2 ± 0.3 km/s with a dispersion $\sigma = 1.0$ km/s. When we consider separately the stars belonging to each individual cluster we obtain $V_r = 271.5 \pm 0.4$ km/s ($\sigma = 1.0$ km/s) and 270.6 ± 0.4 km/s ($\sigma = 0.9$ km/s) for NGC 2136 and NGC 2137, respectively. The two measurements are fully compatible at a level of $1.6\sigma^4$ and also compatible with the LMC velocity distribution, which peaks at ~ 257 km/s ($\sigma = 25$ km/s, Cole et al. 2005). No previous measurements of radial velocities of member stars in these clusters were available in the literature.

The average iron content is $[\text{Fe}/\text{H}] = -0.40 \pm 0.01$ dex and -0.39 ± 0.01 dex for NGC 2136 and NGC 2137 respectively. These are the very first direct measurements of chemical abundances in these clusters since previous estimates of the metallicity were based only on photometry. Both Hilker, Richtler & Stein (1995) and Dirsch et al. (2000) derived lower metallicities ($[\text{Fe}/\text{H}] = -0.55$ dex with a typical uncertainty of about 0.2 dex). Table 1 lists the abundance ratios for each individual star and Table 2 lists the average abundances for the measured chemical elements. As can be seen the two clusters share virtually identical abundance patterns either in terms of iron, α - and light elements. In particular, all the $[\alpha/\text{Fe}]$ abundance ratios are roughly solar, pointing out that the gas from which both clusters formed has been enriched also by Type Ia Supernovae ejecta, as expected given their young age.

This is the first clear-cut indication that stars in the two clusters are virtually indistinguishable both in terms of metallicity and radial velocity. Also, this is the first time that the real nature of a binary cluster is revealed.

Note that the star observed in the possible third component of the system (plotted as a black circle in the left panel of Fig. 1) has $V_r = 281.4$ km/s and an iron content $[\text{Fe}/\text{H}] = -0.54$ dex, incompatible with the chemical and kinematical properties of the two clusters: this seems to exclude a link between this star and the two clusters. At present, we are not able to assess if this stellar association is really bound to the other two clusters, hence we exclude it from the following discussion.

³Note that star #51 is located in the halfway between the two clusters and we decide to consider it member of NGC 2137.

⁴If we attribute star #51 to NGC 2136 (instead of NGC 2137) the results change by ~ 0.1 km/s only.

5. Discussion

From the analysis of the kinematical and chemical properties of the two clusters we obtained two relevant findings:

(i) - *All the measured stars share very similar V_r : indeed, the difference between the average values in the two clusters is only $\Delta V_r = 0.9$ km/s.* Such a small value well agrees with the criterion by Van den Bergh (1998) for the gravitational link of two stellar systems. In order to compute the orbital velocity of the binary system, we first estimated the cluster masses. The SIMBAD database provides integrated V magnitudes of 10.70 and 12.66 for the main and secondary cluster respectively, corresponding to $L_V^{2136} = 1.13 \cdot 10^5 L_\odot$ and $L_V^{2137} = 1.85 \cdot 10^4 L_\odot$. Adopting the mass-to-light ratio of $M/L_V = 0.119$, appropriate for a simple stellar population of 100 Myr, $Z = 0.008$ and solar-scaled chemical composition computed from the BaSTI database⁵, we obtain masses of $M_{2136} = 1.34 \cdot 10^4 M_\odot$ and $M_{2137} = 0.22 \cdot 10^4 M_\odot$ (with a mass ratio of 0.16)⁶. With these mass values and by assuming a circular orbit and $R_{3D} = \sqrt{3/2} R_p$, (where R_p is the projected distance, with $R_p = 19.5$ pc) as a statistical proxy of the de-projected, three-dimensional distance, the orbital period can be easily inferred from the third Kepler's law, yielding a value of $P_{orb} \sim 87$ Myr. Finally, the orbital velocity (computed as $V_{orb} = 2\pi R_{3D}/P_{orb}$) turns out to be $V_{orb} \sim 1.7$ km/s. This value indicates the maximum expected difference between the velocities of the two clusters. Such a small value is in excellent agreement with the observations and enforce our statement that the two objects are gravitationally bound.

(ii) - *The two clusters share the same chemical abundances and abundance pattern, in terms of iron and α - elements, suggesting that they likely formed from the collapse of the same (chemically homogeneous) molecular cloud.* Interestingly enough, the two clusters also show similar and homogeneous abundances of the light elements (Na, O, Mg and Al), at variance with the old GCs in our Galaxy (see e.g. Carretta et al. 2009) and in the LMC (Mucciarelli et al. 2009), which show clear spreads and some anti-correlations. Such a lack of abundance spread among light elements has been already found in a few other LMC GCs of young/intermediate ages (Ferraro et al. 2006; Mucciarelli et al. 2007, 2008) with metallicity similar to the NGC 2136/NGC 2137 pair. From this point of view, the LMC GCs younger than ~ 3 Gyr behave like the Galactic open clusters, that do not show evidences of abundance anomalies (see e.g. de Silva et al. 2009; Martell & Smith 2009).

This finding seems to indicate that while older globulars in both our Galaxy and in the LMC self-enriched at the very early stage of their formation (in the age range between 20 Myr and 300 Myr, see Renzini 2008), and were much more massive in the past (see e.g. D'Ercole et al. 2008;

⁵<http://albione.oa-teramo.inaf.it/>

⁶Note that McLaughlin & van der Marel (2005) derived a slightly higher mass for NGC 2136 by fitting the surface brightness profile: they obtained $M_{2136} = 1.99 \cdot 10^4 M_\odot$, $2.19 \cdot 10^4 M_\odot$ and $2.09 \cdot 10^4 M_\odot$ adopting the King, power-law and Wilson model, respectively. Since no estimate was obtained for NGC 2137, in the following we will adopt the masses derived from the integrated V magnitudes.

Vesperini et al. 2010; Conroy & Spergel 2011) to be able to retain the stellar ejecta, younger and less massive clusters did not undergo self-enrichment processes and their present-day mass should be very similar to their initial mass (see the discussion in Mucciarelli et al. 2011). Thus, the observational evidences presented here confirm the theoretical predictions that clusters with initial mass below $10^5 M_\odot$ should be chemically homogeneous (see Bland-Hawthorn, Krumholz & Freeman 2010). It is worth to notice that stellar clusters with ages of ~ 100 Myr and masses of $\sim 1\text{--}5 \cdot 10^4 M_\odot$ are lacking in our Galaxy, the open clusters in the Milky Way being at least 1 order of magnitude less massive than the coeval LMC globulars. Hence, the study of such young LMC clusters appears to be particularly illuminating to understand the early evolution of the globulars.

Concerning the final fate of the NGC 2136/NGC 2137 system, two possible scenario can be prospected: (i) the two clusters will finally merge under the action of the dynamical friction; or (ii) the mutual tidal forces will disrupt the less massive system, dispersing its stellar content (and probably leaving a weak stellar stream around the survived cluster).

The dynamical friction timescale, hence the time for the secondary cluster to spiral into the main cluster, can be estimated with Eq.7-26 of Binney & Tremaine (1987), assuming the present-day conditions. We derive a merging time-scale of ~ 38 Myr, comparable with the orbital period. However, this scenario is reliable only if the secondary cluster crosses the main cluster: McLaughlin & van der Marel (2005) derive for NGC 2136 a tidal radius of 30.9 pc by adopting a King model, larger than the projected distance between the two clusters (~ 20 pc). Hence, we can consider realistic the occurrence of dynamical friction between the two objects. Alternatively, NGC 2137 will be destroyed by the tidal field of NGC 2136, in a time-scale of ~ 2 Gyr, estimated by adopting Eq. 1 by Gieles, Lamers & Baumgardt (2007). Due to the uncertainty in the mass values and in the 3-D distance, these calculations should be considered as a first-order estimation of the timescales.

The perspective of a merging is quite interesting in light of the formation history of the LMC GCs. Numerical simulations by Makino, Akiyama & Sugimoto (1991), de Oliveira, Bica & Dottori (2000) and Bekki et al. (2004) predict that the final merger of a binary cluster would be indistinguishable from a genuine single-population GC, but with high values of ellipticity ($\epsilon = 0.25\text{--}0.35$), very similar to those observed in the LMC GCs (see e.g. Geisler & Hodge 1980; Mucciarelli et al. 2007). In this framework, we cannot exclude that a fraction of the present-day single LMC clusters were originated by the merging of twin objects (in terms of kinematics, age and chemical composition).

6. Conclusions

The analysis of the kinematical and chemical properties of the pair NGC 2136/NGC 2137 presented in this paper demonstrate that the two clusters share not only the same age (Hilker, Richtler & Stein 1995; Dirsch et al. 2000) but also the same chemical and kinematic *DNA*, unequivocally ensuring

their common origin. *This is the first firm validation of the true binary nature of a LMC cluster pair*: the previous hints were in fact only based on their projected distances and photometric properties. From the obtained results we can also draw a general scenario for the formation and evolution of this binary system. Summarizing: (i) the two clusters formed from the fragmentation of the same molecular cloud; (ii) the chemical composition of the clusters is about the same, without hints of self-enrichment or mutual chemical pollution; (iii) the present-day orbital parameters suggest that the system will merge due to the dynamical friction in a timescale comparable with its orbital period.

An important point to tackle is the different frequency of candidate binary clusters in the LMC and in the Milky Way. Theoretical models by Fujimoto & Kumai (1997) and Bekki et al. (2004) demonstrate that binary stellar clusters can be formed during high velocity cloud collisions. Concerning the LMC, the rate of cloud collisions is mainly triggered by the mutual tidal interaction between the LMC and the SMC, and their close encounters (the last one occurring ~ 200 Myr ago Bekki & Chiba 2005). On the other hand, the Galactic disk is less disturbed by the near tidal fields, at variance to the LMC (that suffers of the effects due to the interaction with the Galaxy and SMC fields), and the rate of cloud-cloud collisions is less efficient, as demonstrated by the dearth of binary systems among the Milky Way open clusters. Thus, the occurrence of binary clusters is intimately linked to the star formation history of their parent galaxy and the interactions of the latter with near tidal fields.

Our findings indicate that other candidate cluster pairs in the LMC could be probed to be binary systems through the analysis of high-resolution spectra. Direct kinematical and chemical measurements of such systems (with both similar and different component clusters ages) are mandatory to assess the origin of these systems and enlighten on the cluster formation history in the Magellanic Clouds.

We warmly thank the anonymous referee for his/her suggestions in improving the paper. This research is part of the project COSMIC-LAB funded by the European Research Council (under contract ERC-2010-AdG-267675).

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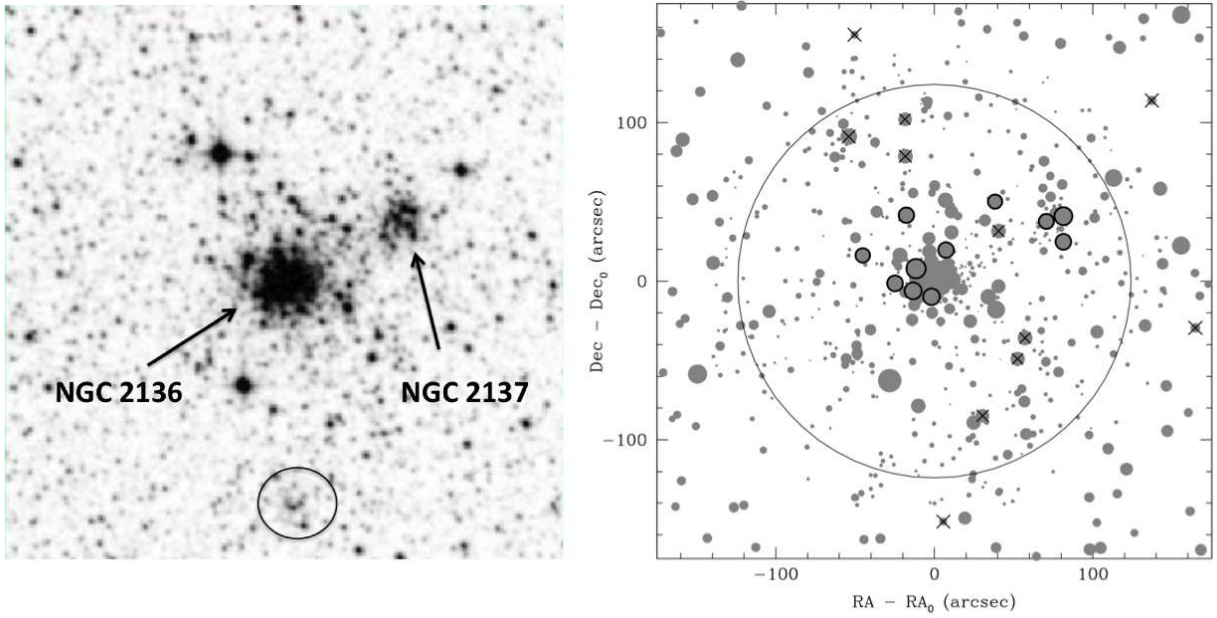


Fig. 1.— *Left panel:* V-band image of the NGC 2136/NGC 2137 system from the Digital Sky Survey archive. The circle marks the position of the possible third component discussed by Hilker, Richtler & Stein (1995). *Right panel:* map of the IR catalog (Mucciarelli et al. 2006, see text); coordinates are referred to the RA and Dec of the center of NGC 2136 (see Mucciarelli et al. 2006). The FLAMES targets discussed in this paper are marked as big grey circles. Crosses indicate observed GIRAFFE targets excluded because they belong to the Galaxy or to the LMC field. The large circle indicates the tidal radius by McLaughlin & van der Marel (2005).

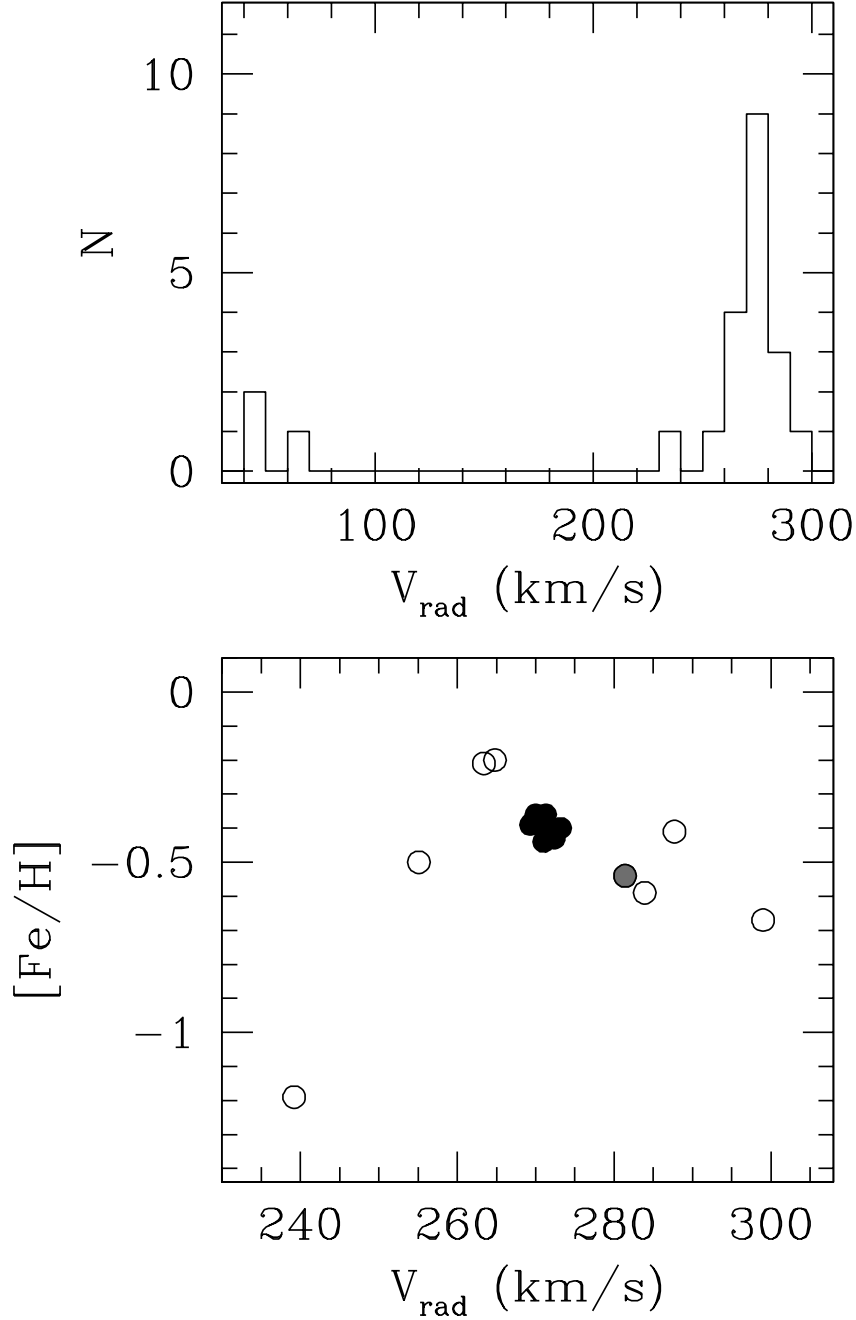


Fig. 2.— *Upper panel:* the radial velocities distribution for the observed targets in the inner 3 arcmin from the center of NGC 2136 (see Fig. 1). *Lower panel:* the distribution of the stars with $V_r > 230$ km/s in the V_r -[Fe/H] plane: black circles are the stars of the cluster pair, the empty circles are the stars belonging to the LMC field and the grey circle is the giant located in the possible third component of the system suggested by (Hilker, Richtler & Stein 1995).

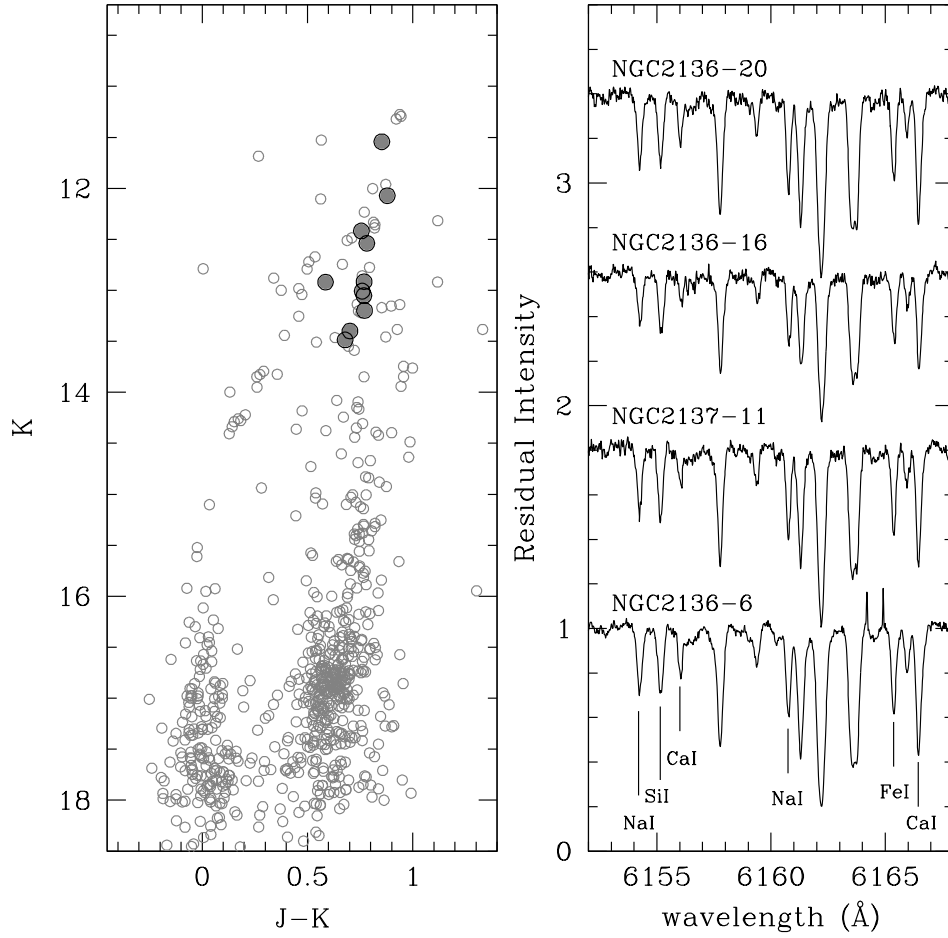


Fig. 3.— *Left panel*: SofI color-magnitude diagram of the field around NGC 2136 and NGC 2137; large grey points mark the spectroscopic targets. *Right panel*: UVES spectra of four stars. A few reference lines are marked.

Table 1.

Star	RA (J2000)	Dec (J2000)	J	K	V_r (km/s)	T_{eff} (K)	log g	v_t (km/s)	[Fe/H] (dex)
NGC 2136-6	88.2319114	-69.4903000	12.39	11.54	271.0±0.5	4100	0.90	2.10	-0.44±0.07
NGC 2136-16	88.2304271	-69.4941896	13.17	12.42	272.4±0.7	4400	1.40	1.50	-0.43±0.07
NGC 2136-20	88.2396754	-69.4952318	13.32	12.54	271.1±0.9	4150	1.20	1.90	-0.39±0.07
NGC 2136-31	88.2214002	-69.4928704	13.68	12.92	271.3±0.5	4400	1.50	1.80	-0.36±0.10
NGC 2136-34	88.2469143	-69.4870399	13.77	13.01	273.2±0.5	4400	1.50	1.70	-0.40±0.09
NGC 2136-35	88.2270944	-69.4809438	13.82	13.05	271.7±0.8	4400	1.60	1.80	-0.40±0.05
NGC 2136-46	88.2052808	-69.4879732	14.04	12.92	270.0±0.6	4550	1.80	1.50	-0.36±0.07
NGC 2137-11	88.3056357	-69.4811137	12.95	12.07	271.0±0.4	4350	1.50	1.80	-0.38±0.09
NGC 2137-28	88.3056203	-69.4855993	13.51	12.92	271.1±0.5	5000	1.10	2.50	-0.40±0.05
NGC 2137-41	88.2970989	-69.4820216	13.97	13.20	271.0±0.9	4450	1.80	1.50	-0.40±0.10
NGC 2137-51	88.2714259	-69.4785592	14.16	13.49	269.3±0.6	4750	1.90	1.60	-0.39±0.08
Star	[O/Fe] (dex)	[Na/Fe] (dex)	[Mg/Fe] (dex)	[Al/Fe] (dex)	[Si/Fe] (dex)	[Ca/Fe] (dex)	[Ti/Fe] (dex)	[Ni/Fe] (dex)	
NGC 2136-6	0.04±0.05	-0.23±0.06	0.06±0.08	-0.03±0.06	0.12±0.10	-0.07±0.08	-0.08±0.10	-0.16±0.05	
NGC 2136-16	-0.09±0.07	-0.24±0.06	-0.02±0.07	-0.07±0.07	0.05±0.12	-0.04±0.08	-0.08±0.07	-0.18±0.05	
NGC 2136-20	0.00±0.04	-0.23±0.08	0.02±0.10	-0.12±0.08	0.16±0.11	-0.07±0.10	-0.11±0.08	-0.18±0.05	
NGC 2136-31	0.02±0.06	-0.22±0.05	0.01±0.08	-0.10±0.06	0.09±0.12	0.00±0.07	-0.09±0.12	-0.20±0.05	
NGC 2136-34	-0.03±0.06	-0.23±0.08	0.04±0.11	-0.08±0.06	0.13±0.09	0.01±0.10	-0.09±0.10	-0.13±0.06	
NGC 2136-35	-0.01±0.08	-0.21±0.06	-0.05±0.07	—	0.04±0.12	0.04±0.10	-0.13±0.09	-0.09±0.06	
NGC 2136-46	0.02±0.07	-0.27±0.05	-0.08±0.07	—	0.04±0.11	-0.09±0.12	-0.14±0.12	-0.16±0.07	
NGC 2137-11	-0.03±0.06	-0.18±0.06	0.02±0.12	-0.08±0.06	0.12±0.10	-0.03±0.11	-0.08±0.12	-0.15±0.05	
NGC 2137-28	-0.07±0.08	-0.22±0.07	0.05±0.11	—	0.01±0.10	-0.08±0.07	-0.18±0.14	-0.20±0.05	
NGC 2137-41	0.03±0.09	-0.36±0.07	0.05±0.09	—	0.21±0.12	0.01±0.12	-0.14±0.10	-0.17±0.07	
NGC 2137-51	0.00±0.07	-0.24±0.08	0.01±0.10	—	0.08±0.08	0.02±0.10	-0.02±0.12	-0.15±0.06	

Note. — Main information of the member clusters stars. Coordinates and magnitudes are from Mucciarelli et al. (2006). The uncertainties in V_r include the internal error and the uncertainty in the wavelength calibration zero-point. The abundance uncertainties include the internal error and that due to the atmospheric parameters.

Table 2.

Ratio	NGC 2136		NGC 2137	
	mean	σ	mean	σ
[Fe/H]	-0.40	0.03	-0.39	0.01
[O/Fe]	-0.01	0.04	-0.02	0.04
[Na/Fe]	-0.24	0.02	-0.25	0.08
[Mg/Fe]	+0.00	0.05	+0.03	0.02
[Al/Fe]	-0.08	0.03	-0.08	—
[Si/Fe]	+0.14	0.05	+0.15	0.08
[Ca/Fe]	-0.03	0.05	-0.02	0.04
[Ti/Fe]	-0.10	0.02	-0.10	0.07
[Ni/Fe]	-0.16	0.04	-0.17	0.02

Note. — Solar reference abundances are from Grevesse & Sauval (1998), with the exception of the oxygen (Caffau et al. 2010).